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AUTOMATIC SKY QUALITY ASSESSMENT. I. THE POINT MEASUREMENT DEVI--ETC(U)
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**Automatic Sky Quality Assessment
I. The Polar Measurement Device**

Prepared for the Department of the Air Force
under Electronic Systems Division Contract F19620-70-C-0002 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

AUTOMATIC SKY QUALITY ASSESSMENT
I. THE POINT MEASUREMENT DEVICE

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Group 94

PROJECT REPORT ETS-38

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ABSTRACT

An automated photometer designed to measure atmospheric extinction and sky brightness has been implemented. The measurement routines are primarily under computer control and require a minimum of operator intervention. A description of the theory and operation of the system is given, and the text concludes with a discussion of the use of the automated system in the context of the GEODSS mission.

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I. INTRODUCTION

The GEODSS mission involves the detection and measurement of artificial satellites at optical wavelengths. Because the measurements must be made through the earth's atmosphere, the optical properties of the atmosphere affect the accuracy and difficulty of these measurements. Interpretation of the results of GEODSS operations therefore requires knowledge of the atmospheric properties.

On any given night there are typically many more possible observations than can be scheduled. Operation of the GEODSS system thus requires a means of allocating observing time amongst a subset of the possible observations. The expected accuracy of a measurement or the anticipated probability of success of an attempted detection depends upon several factors including the optical properties of the atmosphere.

The Automatic Sky Quality Assessment (ASQA) at the ETS has been developed to meet the need of the GEODSS system for atmospheric data to be used for interpreting and planning observations. This report describes that part of the system designed for accurate measurement of point values of the atmospheric properties. Section II explains the theory behind the measurements and the limitations to the accuracy of the derived properties. Sections III and IV describe the setup and operation of the system. Finally, in Section V examples of operation and its application to the GEODSS mission are given.

Also to be included in ASQA is a panoramic device designed for low resolution measurement of the whole sky. This device is in the developmental stage and will be described in a future report. In order to make good use of this device, and in order to apply the measurements to GEODSS planning, a substantial set of operational data will be needed. The final implementation of ASQA will thus require extensive observation with the point measurement device.

II. THEORY

When light passes through the atmosphere, some of it is absorbed and some is scattered. A result of this is that the intensity of a beam of light is decreased according to the relation

$$dI = -I\kappa dx,$$

where x is measured parallel to the direction in which the light is propagating, and κ is an extinction parameter which in general depends on wavelength and position. The intensity actually measured will then be

$$I' = I_0 \exp(-\int_{-\infty}^0 \kappa dx).$$

Here we introduce the convention that a primed quantity refers to the value of that quantity as measured at the earth's surface, and the naught subscript refers to the value of a quantity as measured at the "top" of the earth's atmosphere. Using the definition of the astronomical magnitude, we can write

$$m' - m_0 = \frac{2.5}{\ln 10} \int \kappa dx.$$

It is not practicable to determine κ well enough to allow the integral to be evaluated. Instead we make the assumption that we can write the extinction:

$$m' - m_0 = k_1 X,$$

where k_1 is the extinction coefficient assumed to apply to the whole atmosphere and X is the "air mass" assumed to be a function of zenith distance only. Obviously this is a great oversimplification

of the extinction process, and the statement that a night is of some specific photometric quality is in essence a statement as to how well the assumptions hold.

The simplest approximation for the air mass is obtained by treating the atmosphere as a homogeneous, finite, plane parallel layer. Then the ratio of the length of a slant path to the thickness is just

$$X = \sec z,$$

where z is the angle to the normal - i.e., the zenith distance. Generalizing slightly to the case of an atmosphere of indefinite thickness but with density (and thus κ) decreasing upwards or even stratified into overlapping layers of variable density yields the same result as long as everything is a function of height only. Accounting for the curvature and refraction, however, makes the calculation much more difficult. There is a variety of polynomials in $\sec z$ as well as semi-empirical tables which have been developed in an attempt to produce reliable values of X . Some of the important extinction parameters are so variable that any assumption as to their distribution is unlikely to provide much better results than the simple geometrical calculations. Because of the increasing uncertainty in X and the increasing random error at large zenith distance, it is generally not worthwhile trying to do photometry or measure extinction at values of the air mass greater than about three or four. A satisfactory plan is to evaluate the air mass using a relation

of the form

$$X = \sec z [1 - a(\sec^2 z - 1)]$$

and to restrict photometric measurements to elevations above 15° to 20° . This turns out to be no great loss, because the unfavorable values of sky brightness, total extinction, and atmospheric seeing at low elevations make observations of faint satellites there difficult or impossible.

Thus far we have ignored the wavelength dependence of the quantities. In fact k will be different for different values of λ , and the magnitudes measured will be integrations over a more or less wide bandpass in λ :

$$m' = c - 2.5 \log \int I_o(\lambda) 10^{-.4k(\lambda)X} R(\lambda) d\lambda ,$$

where $R(\lambda)$ is the instrumental response profile. In contrast to the simple relationship between m' and X in equ. (1) we now have

$$m' - m_o = -2.5 \log \{ \int I_o(\lambda) R(\lambda) 10^{-.4k(\lambda)X} d\lambda / \int I_o(\lambda) R(\lambda) d\lambda \} \quad (2)$$

Equ. (2) is obviously intractable, but a useful result can be obtained if we make a few simplifications. Writing

$$\left. \begin{aligned} I_o(\lambda) &= I_o(\lambda_c) [1 + a(\lambda - \lambda_c)] \\ k(\lambda) &= k_c [1 + b(\lambda - \lambda_c)] \end{aligned} \right\} *$$

* The quantity a plays the role of an object color, large positive values of a corresponding to very red appearing objects. The quantity b does the same thing for extinction, but in the opposite sense, with positive values of b corresponding to extinction which causes an object to appear bluish. At a wavelength of 5000A and for a filter 800A "wide", using solar photon flux and standard atmospheric extinction we have $a \sim +.05$ and $b \sim -.15$.

$$R(\lambda) = \begin{cases} 1 & \text{if } \lambda_c - \sigma \leq \lambda \leq \lambda_c + \sigma \\ 0 & \text{otherwise} \end{cases}$$

$$q = .4 \ell n 10 = .92 \dots$$

we can evaluate equ. (2) as follows

$$\begin{aligned} m' - m_0 &\approx -\frac{1}{q} \ell n \frac{\int [1 + a(\lambda - \lambda_c)] \exp\{-qk_c [1 + b(\lambda - \lambda_c)] X\} d\lambda}{\int [1 + a(\lambda - \lambda_c)] d\lambda} \\ &\approx k_c X - \lambda_c k_c X b - \frac{1}{q} \ell n \frac{\int [1 + a(\lambda - \lambda_c)] \exp(-qk_c X b \lambda) d\lambda}{\int [1 + a(\lambda - \lambda_c)] d\lambda} \\ &\approx k_c X - \frac{1}{q} \ell n \frac{(1 + a/qk_c X b) \sinh(qk_c X b \sigma) - a \sigma \cosh(qk_c X b \sigma)}{qk_c X b \sigma} \end{aligned}$$

As a check at this point we use the first terms in the series expansions for sinh and cosh to evaluate the extinction in the extremely narrow band case (i.e., for $\sigma \rightarrow 0$)

$$\begin{aligned} m' - m_0 &= k_c X - \frac{1}{q} \ell n \frac{(1 + a/qk_c X b) (qk_c X b \sigma) - a \sigma}{qk_c X b \sigma} \\ &= k_c X \end{aligned}$$

as expected - i.e., only monochromatic extinction of equ. (1) remains. Including the next term in the sinh and cosh series gives

$$\begin{aligned} m' - m_0 &\approx k_c X - \frac{1}{q} \ell n [1 + qk_c X b \sigma (\frac{1}{6} qk_c X b \sigma - \frac{1}{3} a \sigma)] \\ &\approx k_c X - k_c X b \sigma (\frac{1}{6} qk_c X b \sigma - \frac{1}{3} a \sigma) \end{aligned}$$

This result suggests that we approximate the extinction by:

$$m' - m_o = (k + k'C)X + k''X^2 \quad (3)$$

where C is a color index for the object and the three k 's are to be determined from the observations. If several stars are measured at a variety of air masses then we have

$$(m' - m_o)_{ij} = (k + k'C_i)X_j + k''X_j^2$$

for the j th observation of the i th extinction star. A regression of m'_{ij} against X_j gives $(k + k'C_i)$, m_{oi} , and k'' and a second regression of $(k + k'C_i)$ against C_i gives k and k' . In this way, both the atmospheric parameters and the top-of-atmosphere values of object magnitude can be determined. Once the atmospheric parameters are known, single observations of additional program objects can be corrected for extinction using equ. (3). The m_{oi} derived may be used to build up a catalog of standard reference stars. Such a catalog defines the natural measurement system, allows transformation to other systems, and facilitates extinction measurements as described below.

There are several drawbacks to the scheme outlined above. The regression technique assumes that the derived parameters are constants. The extinction coefficient k , however, can be expected to vary and the derived k will be some sort of mean value. Only if extinction stars and program objects are observed with

very similar distributions in X and time will the same mean values apply to both types of observation. In particular, a mean k will not be the best value to apply to a single observation of a program object. Except on nights of high photometric quality, the quantity desired is the instantaneous point value of the extinction in the neighborhood of the program object. A second drawback is the requirement for a rather large amount of time to perform the extinction measurements. The GEODSS mission requires a high operating efficiency and thus every means of reducing time spent on extinction should be pursued. A third drawback has to do with the colors and bandpasses of the ETS photometer and will be dealt with below.

There are currently two "systems" being utilized for ETS photometry. Both of these consist of a single rather wide passband. Because there is only one passband, there is no color information available and the first term in equ. (3) must be modified:

$$(k + k'C)X + k_1X.$$

Actually, there is a three color system available, but its use will be far more time consuming. Utilization of the three color system will, therefore, be the exceptional case so we will consider only the single passband systems here. The fact that the passbands are quite wide means that the approximations made in arriving at equ. (3) are less likely to hold. Presumably for this reason it has been found to be very difficult to obtain

reliable values of k'' . We are thus forced to return to equ. (1) for our description of extinction. This applies only to operational observing; construction of the catalog must be based on equ. (3), using external color information.

Having constructed a catalog and having settled on a mathematical model of the extinction, we can make extinction measurements using two techniques. We have a photometer with output, y , proportional to the object intensity.

$$y = \alpha I'$$

From this a magnitude is calculated for each of a dozen or so catalog stars:

$$\begin{aligned} m' &= C - 2.5 \log I' \\ &= (C + 2.5 \log \alpha) - 2.5 \log y \\ &= z - 2.5 \log y, \end{aligned}$$

where z is the instrumental zero point which is assumed to be stable during a given night. Combining this with equ. (1) we have for the i th star:

$$m_{oi} + 2.5 \log y_i = z - k_1 X_i, \quad (4)$$

and a regression of y_i against X_i provides values for z and k . The value of k is, of course, an all-sky mean. The catalog stars should all be bright enough so that this measurement can be performed during astronomical twilight, while the sky is still too bright for GEODSS observations. If the night is of high photometric quality, it will be possible to use this value of k

for the whole night. In the more likely event that the sky is patchy or changing with time an instantaneous point measurement of k will be needed.

By far the simplest measurement of extinction is obtained by measuring a catalog star and using equ. (4). Then we have

$$k_1 = (z - m_{01} - 2.5 \log y_1) / X_1.$$

Measurement of a few catalog stars near the program object should quickly provide a reasonably reliable value for the extinction. It is easy to calculate the error made by using equ. (1) instead of equ. (3) to represent the extinction. For the catalog star and program object we have

$$E_c = (k + k'C_c)X_c + k''X_c^2$$

and

$$E_p = (k + k'C_p)X_p + k''X_p^2$$

However, we use equ. (1) to estimate E_p :

$$\begin{aligned} \tilde{E}_p &= E_c (X_p / X_c) \\ &= (k + k'C_c)X_p + k''X_c X_p, \end{aligned}$$

so

$$\delta E = k'X_p (C_c - C_p) + k''X_p (X_c - X_p).$$

Inserting typical values for the constants gives typical errors of less than about $0^m.02$. This error could not be tolerated in most astronomical applications, particularly since it is systematic in nature. For the GEODSS operation, however, this is not a

serious problem and is far outweighed by the advantages of a measurement which can be made quickly and in variable skies. It must be emphasized that this figure represents only the error introduced by this simplification in technique. Several additional unavoidable sources of error will contribute to the uncertainty in the final result of a brightness measurement.

As mentioned at the beginning of this section, the earth's atmosphere scatters light. Scattered light from stars and the moon combine with light emitted by the upper atmosphere to make "dark sky" actually a more or less bright background. The background contribution must be taken into account when brightness measurements are made so the y used above must actually be y (object in sky) - y (sky alone). This is easy to do, but the sky brightness limits the magnitude which can be accurately measured. More important, for GEODSS operations, the sky brightness limits the ability of the video sensors to detect faint objects. The system performance is thus strongly affected by sky brightness. The background light is parametrized by a magnitude, m_b , defined

$$m_b = z - 2.5 \log y_b.$$

It should be noted that this is an instrumental magnitude, uncorrected for extinction. Since this light originates in the atmosphere rather than passing through from outside a correction for extinction seems inappropriate. Furthermore, if such a

correction were made we would have the rather peculiar situation that two patches of equally bright sky would, in general, have differing values of m_b .

As it stands now, m_b measures the light from that patch of sky defined by the field stop that happens to be in the telescope. The usual practice is to add in a correction to normalize this value to a field stop of one square arc-second area. The resulting unit of sky brightness is thus magnitudes per square arc-second. For example, a typical dark sky might have $m_b = 21.0$ /sq. arc-sec. If the field stop was a circular aperture with a diameter of 30", the background light would produce a response equivalent to a magnitude of 13.9 . In this case the correction is $+7.1$. The normalized sky magnitude is thus

$$m_{ob} = z - 2.5 \log y_b + 2.5 \log K,$$

where K is the area of the field stop in square arc-seconds. When the sky brightness is measured, account must be taken of the phototube output for no input - the dark current. Thus y_b must actually be y (sky) - y (dark). Unlike the case with the extinction coefficient, the sky brightness will vary significantly over the sky on even the highest quality nights. Individual measurements are thus needed whenever the value of this parameter is required.

III. EQUIPMENT

There are two sets of hardware which can be used for ASQA. The high speed photometer will eventually be the only one used, but it requires more development before it is really ready for routine use. In the meanwhile the photometer associated with the 6-inch telescope will be used and is the hardware described here. When the high speed photometer is ready, a description of its operation will be issued.

The photometer is attached to a 6-inch telescope which is mounted on the barrel of the 31-inch A-telescope. The telescope focal length is 2.29m and the field stop has a diameter of 2.83mm - equivalent to 4.3 minutes of arc. The light which passes through the field stop strikes the photocathode of an EMI9785B photomultiplier tube. This tube has an S-20 photosurface, the same type as the first surface of the video system. Although it would be unreasonable to expect the spectral sensitivity of the two systems to be identical, it is probably safe to assume that they are close enough so that magnitudes measured on the local photometric system (m_{20}) provide a valid means of evaluating the local video system.

The output from the photomultiplier tube goes to a Pacific Photometric Instruments Model 124 Digital Photometer. This device supplies the high voltage for the photo-tube, amplifies the photomultiplier tube signal current, provides a zero-point offset

for the signal, and provides a digital converted output. This digital output is read by the computer through a set of interface buffers. The operator "aims" the photometer by placing the object of interest on a photo-boresight marked on the monitor.

Appendix 1 gives a detailed description of the equipment and the procedure for getting the equipment properly adjusted for making sky quality measurements.

IV. SOFTWARE

Several programs have been written to handle most of the operation of ASQA as it presently exists. The programs are grouped in an overlay named EXT OV and a task named LEF; these will be described below. The responsibilities remaining to the operator are timely activation of the existing programs, verification that the intended object is in fact on boresight, and, for now, opening and closing the photometer shutter. The "communication" between EXT OV and the operator are carried out *via* the ADDS and buttons programs, run by the real-time system. A description of the actions required of the operator is given in Appendix 2.

The task LEF is a straightforward program involving no observations. When the task is called, the position of the telescope is read from global common. The task then reads a catalog stored on disk and creates a subcatalog of the ten stars nearest to the telescope position. The subcatalog is also named LEF (for local extinction file). When the file is complete, the task exits.

The overlay EXT OV controls three sequences of routines - calibration, extinction, and sky brightness. When the calibration sequence is called, the star catalog is read and a subcatalog of calibration stars is made up. The telescope is then driven to these stars in decreasing azimuth order (so as to minimize the dome motion) and with the operator's assistance measurements are made. The data is then used to calculate the instrumental zero

point and a mean extinction coefficient. When the extinction routine is called, the telescope is driven to stars in the file LEF and, with the operator's assistance, measurements are made. The data is then used to calculate a value for the extinction coefficient applicable to the coordinates of the telescope at the time LEF was called. Finally the sky brightness sequence uses measurements of blank sky and of instrumental dark current, made with operator assistance, to calculate a background magnitude.

V. ASQA IN THE GEODSS MISSION

The purpose of ASQA is to provide data to aid in the interpretation and planning of the nightly GEODSS mission. In the future, the point measurement device will be primarily concerned with data dealing with interpretation, and the panoramic device will be concerned with data for planning. The following examples show how ASQA fits into the GEODSS mission. First, applications of the point measurement device will be examined, and then we will look at application of the panoramic device as supported by a data base built up from measurements with the point device.

Photometric observations will be made primarily for SOI, but also occasionally for system evaluation. The technique used in SOI observations pretty well accounts for the contribution of skylight. Production of accurate SOI data will, however, require correction for atmospheric extinction. On nights of good quality, the mean extinction coefficient from the photometer calibration sequence may be used. On nights of poorer quality, it would be better to run LEF while tracking the object of interest and then to run local extinction. In the case of system evaluation (checking out a new video camera or "calibrating" an MTI device, for example) sky brightness is an important parameter and would be measured as well.

An important function of future GEODSS observations will be maneuver detection. This will consist essentially of merely

failing to acquire an expected object. Such failure to detect, however, might be due to poor atmospheric conditions. Some method of evaluating the effect of the atmosphere upon observations will, therefore, be needed in order to increase the reliability of maneuver detection. This will require the existence of a probability of detection function which, in essence, is a dynamic description of system capability. The probability function will be discussed further below. Given the existence of the probability function, measurement of local extinction and sky brightness can be used to place some specified degree of confidence on a decision that a particular failure to acquire was due to maneuver and not to poor observing conditions.

In an informal way, operators have already taken advantage of an intuitive probability function. Thus on bright or hazy nights, the operators would typically avoid spending great amounts of time searching for objects known to be difficult. Conversely, on unusually dark and clear nights these difficult objects would be given higher priority. For the present, measurements with the point device can quantify "dark" and "clear", and development of the probability of detection function can formalize the procedure. In the future, this task will be turned over to the panoramic device which will interact directly with the scheduling program. Clearly, the most important development is now the probability of detection function.

Assuming that the telescope is correctly pointed at an object of interest, the probability that the operator will detect it depends upon the object brightness, the atmospheric extinction, sky brightness, angular rate with respect to the stars, star density, atmospheric seeing, operator training, and operator fatigue. The introduction of an AMTI device will eliminate the last two variables. With the present resolution, atmospheric seeing is very unlikely to play a significant role, and star density is a known function of position. This leaves us with two sets of variables: those dealing with the geometry of a satellite and its orbit - brightness and rate, and the atmospheric parameters - extinction and sky brightness. Thus, we have probability of detection:

$P(\text{detection}) = P(\text{class of object; true anomaly, sun angle, ...; extinction, sky brightness})$. It may be possible to calculate P on the basis of physical principles. A more fruitful approach is likely to be collection of a large body of detection statistics, and construction of P from this with the aid of an understanding of the physics of the process. Once P is well known, planning/scheduling can be largely turned over to the computer, thus increasing reliability, reducing manpower requirements, and freeing the operators to deal with less easily automated matters.

There are, then, two primary missions for the current ASQAT. First, there is the measurement of the extinction correction for SOI measurements. This is just a straightforward application of

the calibration and local extinction routines. The second mission is the collection of detection statistics. This is probably best accomplished by measurement of local extinction and sky brightness for all marginal detections. It is important to note that for this purpose a marginal detection refers to an object judged to be just barely visible, even if the operator happened to see it right away. It most definitely does not mean an object which required an hour's search to find but was then judged as relatively easy to see. Similar measurements made when an object is not found are potentially useful. Since, however, there are many possible reasons for failure to acquire, the interpretation of such measurements would be ambiguous.

Once a sizeable body of detection statistics and sky measurements has been accumulated, it will be possible to integrate the panoramic device into the system. Data from the panoramic device can be made available to the scheduling program. This program can then estimate the probability of successfully observing the next scheduled object. Observation with low probability of success could then be rescheduled or bypassed entirely thus improving the observational yield.

APPENDIX 1
OPERATION OF ASQA HARDWARE

The main items of hardware for ASQA are the Pacific Photometric Instruments (PPI) 401 Photometric Telescope Coupler (Figure 1) and the PPI Model 124 Digital Photometer (Figure 2). The PPI-401 has had a shutter built into it. The shutter is controlled from the operator's console-bay 4 (Figure 3) by a switch whose use is self-explanatory. Figure 3 also shows the CVI monitor with the photo-boresight marked on it. This boresight mark applies to the ZOOM field of view. Ordinarily the PPI-401 will not need any adjustment. The three cables shown in figure 3 are labeled. The large knob should always be rotated all the way forward as shown, and the two disks should show the number 2 and a white dot.

The PPI-124 requires several adjustments each evening in preparation for operations. (Refer to Figure 2.) There are twelve switches/pots that can be operated:

- #1 POWER - self explanatory
- #2 METER - Three positions - when setting the high voltage at the beginning of operations, this switch must be set at HV. When measurements are being made, this switch must be set at SIGNAL
- #3 HIGH VOLTAGE - range switch
- #4 HIGH VOLTAGE - fine adjustment
- #5 INPUT CURRENT - range switch - always set to 10^{-7}
- #6 SENSITIVITY - switch - always set to OUT

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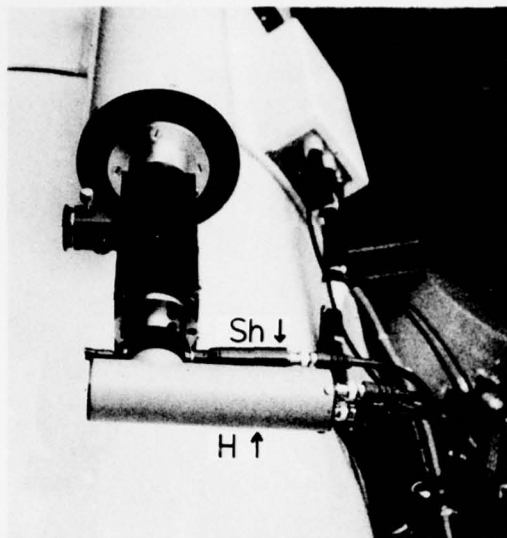


Figure 1a. The PPI-401 Coupler installed on the 6-inch telescope. The cable labeled "SOL" is connected to the shutter solenoid (Sh). The other two cables are connected to the photomultiplier housing (H). Cable #29 connects to S (signal) and cable #92 connects to HV (high voltage). Note the white dot on the filter disk visible about halfway up the 401.

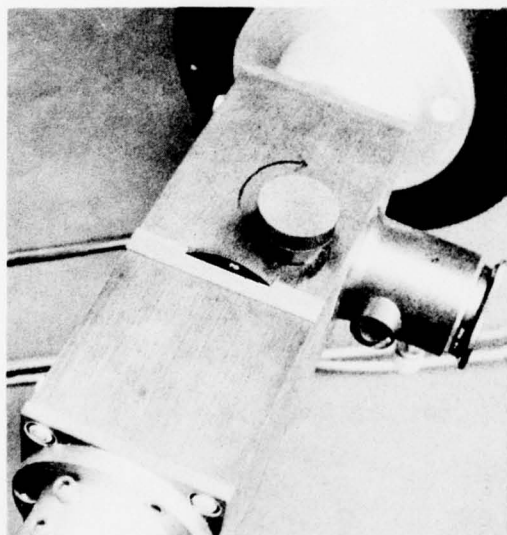


Figure 1b. Close view of the PPI-401. Note the number 2 on aperture disk. The large knob should be fully rotated as indicated by the arrow.

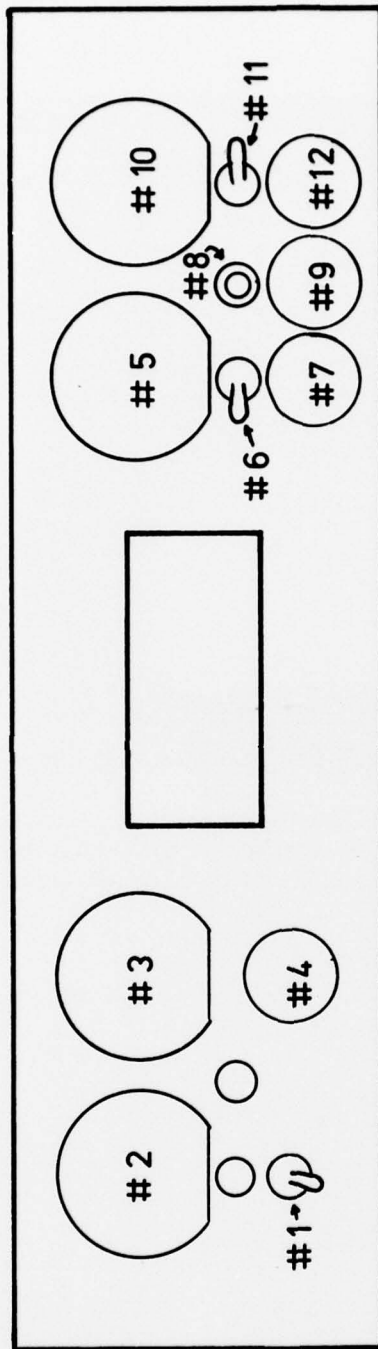


Figure 2. Identification chart for switches on the PPI-124 Digital Photometer.

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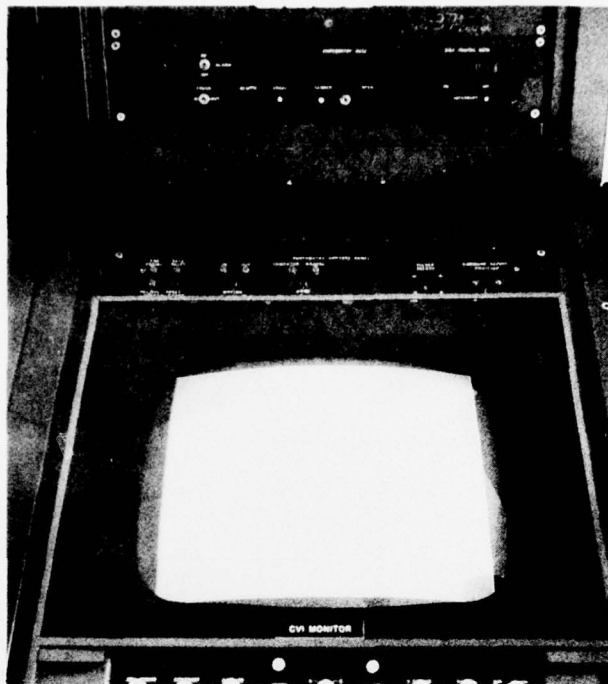


Figure 3. Bay 4 of the A Operator's Console. Note the boresight for the photometer marked on the screen, and the switch for the shutter, just above the monitor, in the closed position.

- #7 SENSITIVITY - pot - not used
- #8 ZERO - pushbutton - not used
- #9 ZERO - pot - not used
- #10 CANCELLATION CURRENT - range switch - always set to 10^{-8}
- #11 CANCELLATION CURRENT - direction switch - always set to OUT
- #12 CANCELLATION CURRENT - fine adjustment

Following is a chronological listing of all hardware adjustments needed for ASQA operation. The timings assume that scheduled GEODSS observations will begin at the end of astronomical twilight - approximately 90 minutes after sunset.

a Approximately one hour before sunset

- make sure PPI-124 HIGH VOLTAGE switch (#3) is OFF
- turn PPI-124 POWER switch (#1) ON
- verify correct settings of switches #5, 6, 10, and 11.
- verify correct setup of PPI-401

b At sunset

- make sure shutter is closed
- set METER switch (#2) to HV
- turn HIGH VOLTAGE range switch (#3) to 500; wait 1 minute
- turn HIGH VOLTAGE range switch (#3) to 1000

c Approximately 40 minutes after sunset

- adjust HIGH VOLTAGE fine adjustment (#4) so meter reads -730

- set METER switch (#2) to SIGNAL
- adjust CANCELLATION CURRENT fine adjustment (#12) so meter reads between 9 and 11
- verify correct placement of boresight on CVI monitor (see below)

d At end of operations

- set HIGH VOLTAGE range switch (#3) to OFF
- turn POWER switch (#1) OFF

In order to verify correct placement of boresight the following procedure must be carried out at the operator's console:

- Drive the telescope to bright star. The star used for initial calibration will do. Remember that the ZOOM field of view must be used.
- Open the shutter.
- Drive the star horizontally and vertically through the center of the boresight mark while watching the PHOTOMETRY DATA meter. It helps to have two people for this. The meter should show a sudden increase just as the star enters the outside circle and a sudden decrease just as the star leaves the outside circle. If this is not true, the location should be adjusted. This is most easily done by moving the picture, using the H. Phase and V. Center knobs at the bottom of the monitor.
- Close the shutter.

It takes some practice to become adept at this procedure.

An experienced operator, however, can do it in two minutes or less.

APPENDIX 2

OPERATION OF ASQA SOFTWARE

Operation of ASQA is effected via four buttons and the ADDS terminal. Once an operating sequence is called, all further action is prompted by messages on the ADDS. The program EXT OV comes up automatically with the Real Time System. The program LEF must be activated separately. To do this the operator should type /LEF on the ADDS. Because of core requirements, it is best to activate LEF only long enough for actual use. The operator should thus activate LEF just before the LEF button is pushed, and deactivate the program immediately after it is finished running (a few seconds). To do this the operator should type /LEF K on the ADDS.

Four buttons, LEF, SKY, EXT, and SKIP STAR are used in running ASQA. The results of a push of each of these follows:

LEF - causes a file to be written for later use by another program.

SKY - causes a message to appear on the ADDS requesting the operator to choose calibration, extinction, or sky brightness. In the case of calibration and extinction the telescope will be driven to a series of stars and messages will appear asking the operator to boresight first the star then sky and in each case to hit the EXT button. In the case of sky brightness, the

messages will ask for sky to be boresighted, then for the photometer to be capped, and in each case for several hits of the EXT button. In all these cases, when enough data have been obtained, the appropriate calculations will be made, and the results reported.

EXT - causes the computer to read data from the photometer.

SKIP STAR - bypasses data taking.

a Calibration

Early in the evening, about 50 minutes after sunset, or as soon as item c in Appendix 1 has been finished, the calibration routine should be run. The operator will perform the sequence given below. The values of various parameters in the ADDS messages are examples only.

Open the Shutter!

Push SKY - the following message will appear on the ADDS terminal:

EXTOV VERS.3: INDICATE DESIRED TEST

(1) PHOTOMETER CALIB (2)LOCAL EXTINCTION (3)SKY BRIGHTNESS

Enter 1 on keyboard - the following message will appear:

273.987 243 0.682 4.287

RA = 13 14 15.6 DEC = 12 12.4 MAG = 4.16 AZ = 5.81

BORESIGHT STAR AND PUSH EXT BUTTON

Put the telescope in TRACK; it will be driven to a bright star. Wait for the dome to catch up Boresight the star - it should be within the inner circle in the ZOOM field - and push EXT. In a few seconds the following message will appear:

BORESIGHT SKY AND PUSH EXT BUTTON

Move the star off boresight - no star should be visible within the outer circle - and push EXT.

The sequence in { } will repeat about 18 times. After the last push of EXT, the following message will appear:

ZERO POINT = -.18 MEAN EXTINCTION COEFFICIENT = 0.31

MODIFICATION COMPLETE

Close the shutter!

There are two possible variations. If the data appears to be suspect, the alarm light will come on and the following message will appear:

MEAN = 438.27 STND = 192.45 PUSH EXT BUTTON AGAIN

BORESIGHT STAR AND PUSH EXT BUTTON

In this case, check that the dome has in fact caught up to the telescope and that the star is properly boresighted; then push EXT again. If the problem has not cleared up, then a visual inspection of the hardware should be made. If this fails to turn up anything out of adjustment, the star should be bypassed using the

SKIP STAR button described next. The second variation is the RARE use of the SKIP STAR button. A push of SKIP STAR in place of EXT will bypass that particular star and return to the top of the sequence in { } for the next star.

b Local Extinction File

While tracking or searching for a satellite, the operator may "decide" to run a local extinction measurement. In order to do this, the task LEF must first be run. To do this the operator performs the following sequence of operations.

Type /LEF on the ADDS keyboard. The following messages should appear:

LEF ACTIVATED FROM PRIMARY FILE

LEF IS ALIVE AND WELL

Push the LEF button. A list of stars will appear on the ADDS.

Type /LEF K on the ADDS keyboard.

(It is anticipated that in the future it will no longer be necessary to activate and deactivate LEF for each use, but that a single activation at the beginning and a single deactivation at the end of the evening will be sufficient.)

c Local Extinction

If LEF has been run, the local extinction may be measured.

The operator must perform the following sequence:

Open the shutter!

Push SKY - the following message will appear:

EXTOV VERS.3 INDICATE DESIRED TEST

(1) PHOTOMETER CALIB (2) LOCAL EXTINCTION (3) SKY BRIGHTNESS

Enter 2 on the keyboard - the following message will appear:

RA=13 34 22.4 DEC=5 17.1 MAG=5.92 AZ=4.83

BORESIGHT STAR AND PUSH EXT BUTTON

Put telescope in TRACK; it will be driven to a bright star.

Wait for the dome to catch up. Boresight the star - it should be within the inner circle in the ZOOM field - and push EXT. In a few seconds, the following message will appear:

BORESIGHT SKY AND PUSH EXT BUTTON

Move the star off boresight - no star should be visible within the outer circle - and push EXT.

The sequence { } will repeat twice more. After the last push of EXT the following message will appear:

LOCAL EXTINCTION COEFFICIENT FOR SAT#=83555 = 0.31 PER
AIRMASS

MODIFICATION COMPLETE

Close the shutter!

Again, the two variations described above may occur.

d Sky Brightness

The sky brightness may be measured at any time by using the following sequence of operations. It would usually be done in conjunction with local extinction.

Open the shutter!

Push SKY - the following message will appear:

EXTOV VERS.3: INDICATE DESIRED TEST

(1) PHOTOMETER CALIB (2) LOCAL EXTINCTION (3) SKY BRIGHTNESS

Enter 3 on the keyboard - the following message will appear:

BORESIGHT SKY, AND PUSH EXT BUTTON

Make sure no stars appear within the outer circle and push EXT. This will repeat three more times. Then the following message will appear:

CAP PHOTOMETER AND PUSH EXT BUTTON

Close the shutter and push EXT. This will repeat three more times. After the final push of EXT, the following message will appear:

NIGHT SKY BRIGHTNESS = 20.72

MODIFICATION COMPLETE

UNCLASSIFIED

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